Mortgage Termination Risk: A Review of the Recent Literature

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Abstract

This paper presents a review and synthesis of the past fifteen years of research on mortgage termination risk. Understanding termination risk is fundamental to explaining the workings of the now $13 trillion mortgage market. The review covers theoretical, empirical, and methodological work, including both residential and commercial market segments. In addition to synthesizing existing findings, open questions for further research are identified. The overall objective is to introduce this important topic to journal readers who may not be actively involved in the mortgage field and to stimulate thinking about open issues that deserve additional research.

Mortgage loans are among the most complex of financial contracts due to the uncertainty of their duration. This uncertainty arises because they may terminate early as a result of either default or prepayment. Default occurs when the borrower cannot, or will not, make contractually promised payments. Prepayment occurs when the loan is paid in full prior to maturity. Causes for these two outcomes are varied, adding to the complexity of explaining and, ultimately predicting, the rate of termination for the loans that are either held in portfolio by financial intermediaries or which provide backing by mortgage-backed securities (MBS). While textbook treatments of this topic (e.g., Clauretie and Sirmans, 1998) typically introduce readers to related industry jargon and provide a few examples of how early termination rates can affect values of mortgage-related assets, the underlying research on termination risk is mentioned only briefly.

To provide a sense of the variation in recent termination rates, consider the following stylized facts on residential mortgages as of December 2006.[1] While the overall rate of serious delinquency[2] for prime single-family mortgages was 0.7%, there was considerable geographic variation, ranging from 0.3% in California to 2.3% in Louisiana. In the subprime segment of the market, the national rate of serious delinquency was 7.8% but as high as 14% in Louisiana and Mississippi; both states recently affected by extensive hurricane damage, of course. In terms of prepayment, prime loans showed a 15.7% rate nationally and subprime loans a 33% rate,[3] much higher than would result from household mobility alone.[4] For comparison, as of fourth quarter of 2006, the delinquency rate for commercial mortgages on bank balance sheets was 1.3% (Federal Reserve, 2006)[5] and the delinquency rate on commercial mortgage-backed securities was at an all-time low of 0.27% (Standard and Poor's, 2007).

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What economic factors produce these results and how do they vary across loan types and over time? Couching the question in an option-theoretic framework, what factors affect exercise of these options and how may those processes best be modeled? I review relevant research, identify major themes, and attempt a synthesis: What do we know and what do we not know? In the process, I will also identify open questions and industry trends likely to produce new answers, and probably new questions, in the future.

I focus on the literature from 1992 to 2007 for several reasons. First, the journal published a previous review (Dickinson and Heuson, 1994), which surveys the early research up to 1992, though limited in focus to prepayments in the residential mortgage market. Second, two frequently cited reviews of default risk were published at about this same time (Quercia and Stegman, 1992; and Vandell, 1993). Finally, the period 1992–2007 has been a particularly dynamic period, with the development of commercial mortgage-backed securities, creation and growth of the subprime residential segment, wide adoption of automated underwriting, and generally low interest rates and robust property values, at least up until the housing market downturn in late 2006.

Why should we be interested in mortgage termination rates? The main objective has been to explain the pricing of mortgages and mortgage-related assets. Theoretical treatments emphasize the competing nature of default and prepayment and may be solved in backward time with computer-intensive numerical procedures, but yield values that generally do not closely conform to observed market prices. Perhaps this is because these represent theoretical asset values over the entire realization of possible economic environments versus conditional values given a particular realization. Alternative valuation approaches include forward-solving Monte Carlo approaches, though these generally ignore default risk and simulate only one stochastic process, interest rates. This appears to be the approach most often used on Wall Street and by major lenders. Resulting values may then be calibrated to market prices by varying term structure simulation parameters or empirical prepayment model sensitivities.

Much of the research has focused on identifying factors that may explain the mismatch between theoretical termination rates and actual observations. Included in this area is research that focuses on the effect of particular borrower or loan characteristics and the effect of the economic environment. The major themes in the literature can be grouped into the following six broad categories:

1. The effects of default and prepayment functions on mortgage valuation.
2. Empirical determinants of defaults and prepayments.
3. Constraints on prepayments; constraints on defaults.
4. The effect of borrower mobility and other non-financial trigger events on termination risk.
5. The effect of unobserved borrower heterogeneity on mortgage termination risk.
6. Methodological issues in implementing valuation algorithms and econometric issues in empirical mortgage termination models.

In following sections, after a brief overview of the mortgage market, I trace out the research over the period surveyed, beginning with the more general theoretical work, and then turn to limitations of the theory, related empirical analyses, and finally methodological research. Most of the work is academic; although some describe models used by investment houses or major lenders, or compares predictions to those generated by such models. Since the literature is voluminous, the review is necessarily limited and selective, but I hope to present a reasonably comprehensive review of the main areas. Before proceeding further, however, it may be helpful to briefly summarize.

Overview of the Research

The theoretical literature tends to focus on asset pricing and generally assumes a homogenous group of rational wealth-maximizing borrowers who can borrow without transaction costs and who are motivated solely by financial considerations. In such models, level of borrower financial sophistication, credit position, institutional constraints, and transaction costs are generally ignored. The commercial mortgage market is thought to be closer to the frictionless ideal of the theoretical models than the residential segment. Empirical research is much more varied, both in terms of focus and methodology, tending to focus more on the heterogeneity of borrowers, lenders, and loan types.

Broad categories of empirical work include that focusing on prepayments, research focusing on defaults, and research addressing both risks jointly. Results may be termination risk prediction, assessment of the effect of particular factors on termination risk probabilities, the termination behavior of particular types of mortgages, or termination risk functions that are then used as inputs for mortgage pricing. Focus has often depended both on the particular market segment and the data available for analysis. For example, since Government National Mortgage Association (GNMA) securities are insured against default risk by the U.S. Government, the consequences of default are of minimal concern to investors, except as such defaults and insurance payoffs appear as unscheduled returns of principal. Since GNMA securities were the first type of mortgage asset to be publicly traded, much of the early research focused on their pricing, ignoring default risk given the credit insurance noted.

Methodological issues apply to both theoretical and empirical work. In the theoretical arena, issues often center on computational methods, whether backward-solving or forward-solving Monte Carlo techniques. On the empirical side, econometric technique and model specification are typical topics, with innovations to the standard hazard modeling framework proposed and evaluated. Of particular interest in the residential segment on the prepayment side has been accounting for unobservable characteristics of loans or borrowers.

The plan for the balance of the paper is as follows. In the next section I briefly describe the commercial and residential sectors of the mortgage market, identify segment-specific contract features that may affect termination risk, and discuss current market trends. The third section reviews the major theoretical literature. In the fourth section, I focus on empirical work, subdividing that literature into several categories. In the fifth section, I focus on methodological research. The sixth section presents a synthesis and identifies open research questions. Exhibit 1 groups selected papers into several categories and may be helpful to readers desiring further reading.

The Mortgage Market

This section briefly describes some of the major features of the mortgage market in the United States, distinguishing the commercial from the residential segment. This

Exhibit 1
Papers on Mortgage Termination by Category

Focus	Methodology
Refinancing Kau and Keenan (1995) Kau et al. (1992, 1995) Stanton (1995) Archer, Ling, and McGill (1996, 1997) Peristiani, Bennett, Monsen, Peach, and Raiff (1997) Deng, Quigley, and Van Order (2000) Downing, Stanton, and Wallace (2001) **Household Mobility** Clapp, Harding, and LaCour-Little (2001) Clapp, Goldberg, Harding, and LaCour-Little (2001) Pavlov (2001) Deng, Pavlov, and Yang (2005) Clapp, Deng, and An (2006) **Default** Quercia and Stegman (1992) Kau, Keenan, and Kim (1993, 1994) Vandell (1993, 1995) Deng, Quigley, and Van Order (1996) Capozza, Kazarian, and Thomson (1998) Kau and Keenan (1999) **Commercial Mortgages** Riddiough and Thompson (1993) Abraham and Theobald (1997) Wheeler (2000) Fu, LaCour-Little, and Vandell (2003) Ambrose and Sanders (2003) **Secondary Financing** LaCour-Little (2004) Agarwal, Ambrose, and Liu (2005) Agarwal, Ambrose, Chomsisengphet, and Liu (2006)	**Multinomial Logit Model** Archer, Ling and McGill (1996) Clapp, Goldberg, Harding, and LaCour-Little (2001) Clapp, Deng, and An (2006) **Cox Partial Likelihood Model** Quigley, Van Order, and Deng (1993) Clapp, Goldberg, Harding, and LaCour-Little (2001) Pavlov (2001) **Competing Risks Hazard Model** Deng, Quigley, and Van Order (2000) Deng and Quigley (2001) **Non-parametric Methods** LaCour-Little, Maxam, and Marschoun (2002) Maxam and LaCour-Little (2001) **Wall Street Models** Patruno (1994) Hayre and Rajan (1995) Hayre, Chaudhary, and Young (2000) Wheeler (2000) Hayre (2001)

will serve as background to the discussion that follows, providing a typology of mortgages and identifying distinct contract features that may be relevant to the research surveyed.

The mortgage market, consisting of all loans collateralized by real property, is often divided into the primary and secondary market. In the primary market, borrowers interact with lenders and third-party loan originators.[6] Loan applications are submitted, interest rates quoted, applications are underwritten, property appraised, and transactions closed. In the secondary market, closed loans are pooled together and sold, often to government-sponsored enterprises (the GSEs: Fannie Mae and Freddie Mac), investment houses, or other market participants, as the raw material for mortgage-backed securities. These may be either agency mortgage-backed securities (MBSs), in which credit risk is guaranteed, or private label securities, in which senior-subordinate structures generally serve to manage credit risk. The latter structure is generally used for commercial mortgages too, since no third-party credit guarantor is available to insure default losses. Pools of mortgages and/or MBSs may be then re-engineered to create mortgage-related derivatives, including interest-only and principal-only strips, collateralized mortgage obligations, or collateralized debt obligations, which may combine mortgage-related assets with other debt types. The purpose of this re-engineering is to re-allocate termination risk, creating tranches of securities that are relatively immune to termination risk or changes in termination rates. Re-engineered securities can be marketed to investor clienteles with particular preferences as to investment horizon, risk, and yield.

By convention, loans secured by one-to-four-family dwelling units are considered single-family properties, whether owner-occupied or not, and are eligible for sale to the GSEs, provided they conform to guidelines, important among which is a maximum loan size (the conforming loan limit). Loans secured by residential income property (multi-family properties) are properties with five or more units and may also be eligible for sale to the GSEs. As income property, however, multi-family mortgages are subject to alternative underwriting standards and are not subject to any legally imposed loan limit. Such loans are considered commercial mortgages, along with loans secured by other types of income property, including the major property categories of office, retail, and industrial uses, which are ineligible for sale to the GSEs. Commercial mortgages are increasingly packaged into commercial mortgage-backed securities (CMBSs) by various secondary market institutions, many of which operate commercial mortgage lending conduits to support their CMBS issuance. The secondary market in commercial mortgages developed later than did the residential segment, but has seen rapid growth over the last fifteen years, now reaching almost $3.0 trillion.

Commercial mortgage contract terms differ from single-family residential mortgages in some important ways. First, because credit insurance is not widely available, they tend to be more conservatively underwritten with lower maximum loan-to-value (LTV) ratios and shorter terms.[7] They also often specifically prohibit subordinate financing. Second, they are more likely to be non-recourse, especially if slated for inclusion in a later CMBS issue. Third, and perhaps most importantly for our topic here, commercial mortgages are much more likely to contain prepayment penalties intended to reduce the risk of refinancing.

As mentioned earlier, the mortgage market is huge. According to the Federal Reserve,[8] as of year-end 2006, total outstanding mortgage debt was estimated to be $13.2 trillion, including $10.2 trillion in single-family, $0.7 trillion in multi-family, and $2.1 trillion in non-residential. Of this amount, about $7.0 trillion[9] had been securitized into mortgage and asset-backed securities, an amount now larger than either the corporate bond or U.S. Treasury markets. The securitized residential segment has been in existence for over thirty years; in contrast, the commercial segment is much newer, first becoming viable with the issuance of CMBS by the Resolution Trust Corporation during the early 1990s as part of the management of the thrift crisis of the late 1980s. Agency securities originated with GNMA[10] in the 1970s, moving to the conventional conforming market in the 1980s, and commercial issues in the 1990s.

Theoretical Literature

Options represent contingent claims that will be exercised under certain states of the economy but not otherwise. In the case of mortgages, the two most obvious sources of uncertainty are the future level of interest rates and the future value of the collateral property. To these one might add the future level of the borrower's income and overall financial position, of course. Ignoring these for the moment, the standard fixed-rate mortgage may be viewed as a straight annuity, or non-callable bond, containing two embedded options written by the lender and held by the borrower: the option to prepay and the option to default, both of which will terminate promised contractual cash flows. With prepayment, the total outstanding loan balance is returned to the lender whereas with uninsured default, there may be, and usually is, some loss of principal, an amount expressed in percentage terms as loss severity. Under this approach, prepayment may be modeled as a call option allowing the borrower to repay the mortgage at the then-current outstanding loan balance and default represents a put option allowing termination of the debt by transferring title to the collateral property to the lender.

Researchers have long applied option-pricing methodologies to the analysis of mortgages. Conceptually, if one could value the two embedded options, the value of the mortgage would be the difference between the option-free instrument and the joint value of the two options.

Kau, Keenan, Muller, and Epperson (1992) is the most widely cited work[11] presenting a general model of fixed rate mortgage valuation, recognizing the competing risks of default and prepayment. Kau et al. sets out what has become the standard two-factor theoretical valuation methodology, allowing for both interest rate and house price uncertainty, while assuming optimal options exercise and no transaction costs. The value of the mortgage net of embedded put and call options is shown to satisfy a partial differential equation for which no closed form solution is available. A solution can be obtained, however, by specifying boundary conditions and using finite difference methods and numerical procedures. Among their findings, Kau et al. note that unless initial loan-to-value ratio (LTV) or house price volatility is quite high, the effect of default risk on mortgage valuation is small compared to the effect of prepayments. This result, that the value of the call option is much greater than that of the put option, persists throughout the literature and helps explain the focus on prepayments, rather than default.

The formal set up for this type of model requires specification of two stochastic processes: the market interest rate, $r(t)$, and the house value, $H(t)$. Mortgage value (V) depends on these two factors. The well-known Cox Ingersoll Ross (CIR) interest rate process[12] may be represented as:

$$d(r) = \gamma(\Theta - r)dt + \sigma_r\sqrt{r}dz_r \tag{1}$$

where Θ is the steady state mean rate, γ is the speed of adjustment factor, and σ_r is the volatility of interest rates. Mortgage value also depends upon house value, $H(t)$, the evolution of which can be described by an analogous diffusion process:

$$\frac{dH}{H} = (\alpha - s)dt + \sigma_H dz_H, \tag{2}$$

where α is the instantaneous total return to housing, s is the service flow, and σ_H is the volatility of housing returns. Here, dz_r and dz_H are standard Wiener processes.

Kau, Keenan, Muller, and Epperson (1992) show that under perfect capital market assumptions, the value of the mortgage (V) satisfies the following partial differential equation (PDE):

$$\begin{aligned} &\tfrac{1}{2}H^2\sigma_H^2\frac{\partial^2 V}{\partial H^2} + \rho H\sqrt{r}\sigma_H\sigma_r\frac{\partial^2 V}{\partial H\partial r} + \tfrac{1}{2}r\sigma_r^2\frac{\partial^2 V}{\partial r^2} \\ &\quad + \gamma(\theta - r)\frac{\partial V}{\partial r} + (r - s)H\frac{\partial V}{\partial H} + \frac{\partial V}{\partial t} - rV = 0. \end{aligned} \tag{3}$$

In Equation (3), the correlation between the movements of the two state variables (dz_H and dz_r) is ρ.

By specifying boundary conditions, the value of the mortgage (V) may be derived solving for default and prepayment determined simultaneously. Numerical results provide comparative statics showing the effect of changing economic parameters on the value of prepayment, default, and mortgage value. This sort of model requires the assumption of rational exercise of the two options. In particular, it assumes that borrowers will default as soon as the value of the collateral property falls below the value of the loan. Likewise, it assumes that borrowers will prepay as soon as value of the mortgage (when calculated at current market interest rates) increases above the par value of the loan.

Kau and Kim (1993) extend this approach focusing on the timing of prepayment without transaction costs and non-financially motivated prepayment. Again solving the partial differential equation in backward time through numerical procedures, as in Kau, Keenan, Muller, and Epperson (1992), an expression for the expected time to prepayment is derived. Similarly, Kau, Keenan, and Kim (1994) focus on default probabilities using similar techniques to derive probabilities that depend on the level of house price volatility, the initial LTV ratio, the coupon rate, and the interest rate environment. Default probabilities over time are shown to depend mainly on initial LTV and house price volatility. For example, the cumulative default probability for a 30-year FRM with a 9% coupon and an 80% initial LTV under 10% house price volatility is estimated to be less than 2% whereas for a 95% initial LTV that probability exceeds 10%. This finding, that default risk is primarily a matter of initial LTV, is another result that persists throughout the literature and which, as we will see in our discussion of the empirical research, was well-established by early studies (Dickinson and Heuson, 1994). A more comprehensive summary of much of the theoretical work that has just been briefly reviewed appears in Kau and Keenan (1995).

Stanton (1995) relaxes some of these more restrictive assumptions and develops a model of mortgage prepayments assuming rational decisions by borrowers who face heterogeneous transaction costs and make prepayment decisions at discrete intervals, rather than continuously, as in other rational models. These two model features produce the "burnout" effect,[13] similar to that noted in other purely empirical work, to which we will turn later. The size of implied transaction costs is very high, however, a result at odds with the perspective that the mortgage market has become more efficient over time and that transaction costs and constraints on prepayment have been declining. For example, empirical work by Todd (2001) finds that loan securitization has driven down transaction costs to consumers, but has not reduced loan rates significantly.

More recently, Hilliard, Kau, and Slawson (1998) apply a bivariate binomial options pricing technique to value default and prepayment options in a fixed-rate mortgage contract. This technique is relatively simpler than the finite difference technique used in Kau, Keenan, Muller, and Epperson (1992), yet results are quite similar, within 2% in terms of the joint option to prepay or default. Again, the value of the prepayment option is shown to be an order of magnitude greater than the value of the default option.

In the commercial mortgage market, the research is more limited. Riddiough and Thompson (1993) develop a pricing model for commercial mortgage debt that incorporates heterogeneous transaction costs that are unobservable to the lender. These unobservable costs help explain why default rates differ from those predicted by ruthless mortgage-default models.[14] They use Monte Carlo simulation to produce numerical mortgage prices that more realistically reflect the default premiums and loss levels observed in the market.

Kau, Keenan, Muller, and Epperson (1990)[15] use modeling techniques similar to those described above to analyze commercial mortgages, where prepayment risk is constrained by early term lock-out provisions and subsequent prepayment penalties. This paper also addresses the differences between outcomes for the mortgages themselves and for MBS investors given the guaranty structure assumed, as the loans examined are multi-family mortgages sold in the secondary market and re-packaged as CMBS with an agency guaranty.

Empirical Complications

The pure option-theoretic approach produces several problems. First, the values generated do not match actually observed market prices for mortgage assets. In particular, theory does not explain why mortgages, or MBSs, often trade at prices well in excess of par value. Dunn and Spatt (2005) document GNMA prices in the 100–115 range during the mid-1980s and FNMA premiums currently trade in the 105–110 range. Second, the default and prepayment rates implied by theory do not match empirical results. In particular, the option-theoretic approach predicts default and prepayment rates that are much higher than those actually observed in practice.[16]

Evidently borrowers do not exercise options as theory would predict. Of course, borrowers may have other, non-financial, motivations for prepaying the mortgage prior to maturity, including sale of the house, household dissolution resulting from divorce, and so forth. Such effects are sometimes characterized as exogenous trigger events and their role in affecting default rates, in particular, has been contentious (more on this later). Causality may be reversed too, as mortgage terms may exert an effect on mobility. The extent to which borrowers fail to exercise in-the-money options has been a topic of much empirical work, especially for prepayment risk.

Another explanation for the apparent under-exercise of mortgage options is borrower heterogeneity. If borrowers have heterogeneous holding periods for the house, the calculation of the expected benefits of refinancing will vary across households. Given transaction costs, it may not make economic sense to refinance an over-market rate loan if the payback period is too short.

Researchers have attempted to address some of these difficulties. For example, Follain, Scott, and Yang (1992) use binomial option pricing methods to develop a model of prepayment behavior when borrowers within mortgage pools have heterogeneous holding periods. In their model, the point at which prepayment is triggered depends on transaction costs, interest rate volatility, and borrower holding period. In an empirical application using data from the 1980s, they provide additional evidence on the extent to which prepayment options are not exercised ruthlessly.

An analogous problem occurs when borrowers fail to default once the value of the collateral property falls below the balance of the loan. This empirical anomaly was demonstrated by Quigley and Van Order (1995), who used data on conventional loans originated between 1975 and 1989, finding that at low levels of negative equity the default option is not immediately exercised. A strong relationship between default rates and LTV is, however, readily apparent. In their raw data, for example, loans with LTVs of less than 75% have a 0.29% default rate, increasing to 1.40% for loans with LTVs of 81%–85% and 4.72% for loans with LTVs from 91%–95%.

The apparent under-exercise of the default option has generated significant debate as to whether such behavior constitutes non-rational behavior on the part of borrowers. Vandell (1995) summarizes the evidence on this question, defining ruthless behavior as immediate default once the value of the collateral falls below the value of the loan. Vandell also presents arguments in favor of a trigger event-based theory, in which negative equity may be a necessary, but not sufficient, condition for default. He also raises the issue of lender-specific influences, since it is ultimately the lender who initiates foreclosure as a remedy to default. For more recent work on the trigger-event theory, see Elmer and Seelig (1999) who argue that the borrower's entire financial position must be evaluated to determine whether default is an optimal choice.

The alternative view of the apparent under-exercise of the default option (or, for that matter, under-exercise of the prepayment option) is that borrowers may rationally delay to avoid forfeiture of the right to exercise the option in the future. Arguments in favor of this view may be found in Kau, Keenan, and Kim (1994), Kau and Kim (1994), and Ambrose, Buttimer, and Capone (1997). Of course, a borrower refinancing into a new mortgage immediately obtains a new pair of options replacing those forfeited, so this forfeiture may be of relatively small economic value.

Institutional Constraints: Prepayment

The apparent under-exercise of the prepayment option produced considerable research on institutional factors and market frictions that might limit prepayment. Among these, Archer, Ling, and McGill (1996) examine the effect of income and collateral constraints on the exercise of the mortgage call option. They find that these constraints are significant and account for nearly all of the explanatory power that might otherwise be attributed to borrower demographic characteristics. Similarly, Archer, Ling, and McGill (1997) consider the role of borrower demographics, turning their focus to mobility related factors, which affect call option exercise in two conflicting fashions. First, high mobility households may call their mortgages when even the option is out-of-the-money. Second, households with short expected tenure may fail to call their mortgages even when the option is in-the-money, due to the shorter horizon over which to realize savings from refinancing and recoup transaction costs.

As an example, Archer, Ling, and McGill (1996), represent the total probability of mortgage termination, λ_{Tt}, for all reasons, as:

$$\lambda_{Tt} = \lambda_{Dt} + (1 - \lambda_{Dt})[\lambda_{Mt} + (1 - \lambda_{Mt})\lambda_{P.NMt}], \tag{4}$$

where λ_{Dt} is the probability of termination due to default at time t, λ_{Mt} is the probability of terminating due to moving at time t, and $\lambda_{P.NMt}$ is the probability of terminating due refinancing in place (prepaying and not moving) at time t. Notice that the last term, $\lambda_{P.NMt}$, is conditional upon not moving. Equation (4) yields insights into the problems with research previously discussed. Option theory can provide explanations for both λ_{Dt} and $\lambda_{P,NMt}$, but is silent with respect to λ_{Mt}.[17] But what we observe using mortgage pool data, and sometimes even with loan level data, is λ_{Tt}. The implicit assumption then is that both λ_{Dt} and λ_{Mt} equal zero, which is surely not the case with heterogeneous borrowers.

Peristiani, Bennett, Monsen, Peach, and Raiff (1997) also focus on the constraints limiting prepayment, arguing that poor credit or low levels of current housing equity both act to limit the ability of borrowers to refinance, even when it would be in their financial interest to do so. Caplin, Freeman, and Tracy (1997) focus on these same factors addressing macroeconomic implications. They argue that house price declines that trigger defaults and constrain prepayments also exacerbate regional recessions, such as those occurring in the Northeast during 1987–1991. Likewise, Green and LaCour-Little (1999) examine the failure to refinance, attributing it to both transaction costs and low levels of housing equity. More recently, Deng and Gabriel (2006) have argued that mortgage loans to lower-income and minority borrowers are more valuable to investors, since the propensity of those groups to prepay is substantially reduced, even though their default risk may be somewhat elevated.

An important development since about 1995 has been the subprime market segment. Subprime loans allow borrowers with various credit, debt, documentation, or collateral problems to readily obtain mortgages, although at significantly higher contract rates and, often, with more onerous contract terms including prepayment penalties. Development of this segment has presumably reduced the effect of constraints on refinancing. The work by Pennington-Cross on loan performance in the subprime market is of particular note (Pennington-Cross, 2003; Pennington-Cross and Danis, 2005; and Pennington-Cross and Chomsisengphet, 2007). In addition, a two volume special issue of the *Journal of Real Estate Finance and Economics* is devoted to the topic of subprime lending (Staten and Yezer, 2004). These papers tend to establish that subprime loans behave differently from traditional prime loans even after controlling for objective risk factors. For example, subprime loans are relatively less sensitive to interest rate changes and equity extraction is a very important element in the subprime segment.

Prepayment: Other Factors

A large body of research has examined other specific factors that may be predictive of mortgage prepayments, both those related to borrower mobility and those related to refinancing. Wall Street firms frequently produce research along these lines, intended to help investors evaluate prepayment risk on MBSs backed by pools of loans with distinct characteristics. These studies typically model the pool level rate of prepayment rather than individual loan level prepayment probabilities, since it is the aggregate pool performance that produces the cash flows to security holders. Dickinson and Heuson (1994) review some of the earlier studies, noting the effect of below or above-expected prepayment rates on MBS yields.

More recent papers describing Wall Street prepayment models, at least in general terms, include Patruno (1994), Hayre and Rajan (1995), Hayre, Chaudhary, and Young

(2000), and Hayre (2001). In these sorts of studies, authors qualitatively describe the factors used in their prepayment model and graphically depict model predictive power (and perhaps yield effect on securities), but do not report actual regression techniques, model specification, or parameter estimates. Today such models are generally updated very frequently (at least annually and sometimes quarterly) and so back testing is difficult. A typical Wall Street pool level model includes five factors that are predictive of prepayment rates: housing turnover rates, seasonality,[18] refinancing incentive, loan age (often called pool seasoning), and burnout. Hall (2000) specifically focuses on burnout as a phenomenon in analysis of mortgage prepayment risk, arguing that burnout is a result of unobservable predictive variables, and develops a mixture model to control for that heterogeneity.

In the academic arena, Schwartz and Torous (1992) also focus on valuation of mortgage pass-through securities, noting that although default risk is typically guaranteed, default affects the timing of cash flows and hence security value. As in Kau, Keenan, Mueller, and Epperson (1992), they allow for two state variables, interest rates and house prices, and consider the effect of credit insurance. In contrast, however, they allow for sub-optimal prepayment exercise, employing an empirically derived prepayment function.

Chinloy (1993) develops a model of consumer behavior to explain the multiple choices available to the mortgage borrower at each point in time: prepay the loan in its entirety, prepay only partially (a phenomenon known as curtailment), default, or continue payment. Empirical results are presented using data from GNMA pools. This paper appears to be the only one to explicitly consider curtailment as a distinct option available to the borrower, with the exception of an unpublished dissertation (Fu, 1997).

Schwartz and Torous (1993) propose Poisson regression as a method for estimating a proportional hazards model addressing both mortgage default and prepayment. They claim that Poisson regression is particularly efficient given the time-varying nature of many of the explanatory factors typically entering default and prepayment functions. The technique is illustrated using Freddie Mac data from 1975 to 1990.

Institutional factors may play a role in mortgage prepayments as well. LaCour-Little and Chun (1999) examine the role of mortgage brokers in the loan origination process. They report that loans originated by brokers are about three times more sensitive to refinancing incentives compared to other loans, a phenomenon consistent with broker churning of customers to generate fees. A related analysis by Alexander, Grimshaw, McQueen, and Slade (2002) focuses on the effect of mortgage brokers on default, also documenting higher levels of mortgage termination when loans were originated by third parties. The effect of the origination channel on subsequent loan performance is a fertile ground for research, since mortgage brokers now originate the majority of all residential mortgages.

Recently researchers have again sought to better disentangle prepayments arising from mobility from those due to refinancing. This issue persists because lenders do not generally receive any explanation from borrowers for their prepayments; rather, they simply receive a request for payoff amount from a third party, often a title company. Representative work in this area includes Clapp, Harding, and LaCour-Little (2000), Pavlov (2000), and Clapp, Goldberg, Harding, and LaCour-Little (2001). The empirical approach generally used is to match data on mortgage terminations to housing market transactions so as to be able to determine whether mobility or in-place refinancing actually occurred. For example, Pavlov (2001) uses data on real property transfers merged with mortgage terminations to determine whether prepayments occurred due to borrower mobility or in-place refinancing, The author uses spatial clustering measures to capture unobserved heterogeneity in borrower refinancing propensity. Among his conclusions are that borrowers in high income areas are more likely to refinance when rates are favorable while lower income households are less likely to refinance but more likely to move or default.

In related research, LaCour-Little (1999) examines prepayment behavior using a unique dataset that contains information on both the refinanced loan and the new loan, sweeping out completely the complications of mobility-driven prepayments. Using this data set, LaCour-Little argues that the role of borrower characteristics in terms of refinancing sensitivity may be overstated and simply reflect differential mobility. Panel data that traces the mortgage product usage of households over time is needed to extend this line of research.

Contract innovation that may alter prepayment risk has been another natural focus of interest. For example, work on prepayments has focused on adjustable rate instruments with initial term discounts (Green and Shilling, 1997; and Ambrose and LaCour-Little, 2001) and hybrid mortgage design (Ambrose, LaCour-Little, and Huszar, 2005). Such studies tend to confirm that unique contract designs produce distinct empirical patterns in prepayment and/or default. In the investment community, this translates into multiple models, one for each major contract type, and difficulty modeling newer contract forms for which experience is not available. As a result, newer contract designs may carry relatively larger price premiums initially, with those premiums for uncertainty declining as loan performance experience is accumulated by market participants. There is some evidence that this has occurred in the subprime segment, with spreads to prime rates declining by perhaps 100 basis points over the period 1995–2005.

Another area of interest has been the role of house prices, particularly during the recent run-up in the housing market from 1995 to 2005. Rising house prices allow borrowers to extract accumulated equity tax-free through refinancing, behavior which may be motivated by factors quite different than those traditionally associated with prepayments (e.g., refinancing consumer debt). Greenspan and Kennedy (2007) argue that such equity extraction support consumer spending during time periods when it otherwise might have declined. Other papers focusing on house price effects include Mattey and Wallace (2001) and Downing, Stanton, and Wallace (2005).

Constraints on Default

Turning to default, constraints have not been studied nearly as thoroughly. Reputation costs, e.g., damage to borrower's credit rating, are often mentioned, but these are hard to quantify. Recourse is another issue identified in Vandell's (1995) original survey on the ruthlessness of mortgage default. If mortgage debt is not fully non-recourse,[19] then exercising the put option may not completely extinguish the debt at all. Moreover, there are negative income tax implications of default as well.[20] There may be an interaction between borrower bankruptcy and mortgage default, too. None of these issues has been adequately explored.

While it is popular to treat default as a put option, it is not an explicit contract option at all. Rather, default represents a breach of the contract, not the exercise of an option contemplated by the contract. And foreclosure, i.e., forfeiture of title to the property, is not an option exercised by the borrower at all, rather it is the remedy exercised by the lender in the event of borrower default. This implies that lender heterogeneity may be as important as borrower heterogeneity in explaining the ultimate outcomes when default does occur. Moreover, it is not simply the original lender's decision, given the unbundling of functions and reallocation of credit risk to specialized institutions. Where a loan has been securitized, there is an investor, a loan servicer, and perhaps a provider of credit insurance, all of whom have a stake in the eventual outcome of any default. This area, too, appears to be a fertile ground for further research.

Other Factors Affecting Default

Quercia and Stegman (1992) characterize first-generation studies as those focusing on the lender's perspective and on loan characteristics, including loan-to-value, housing payment to income, and debt-to-income ratios. They distinguish these from second-generation studies that attempt to model the decision to default from the borrower's perspective (put option exercise), and third-generation studies that focus to a greater extent on institutional perspectives. They argue that the role of loan characteristics is relatively well understood whereas the role of borrower characteristics, including transaction costs, is less well understood.

Vandell (1993) also provides a survey of mortgage default research. Several outstanding issues are identified: (1) the degree of ruthlessness in mortgage default; (2) the effect of recourse; (3) default timing and loss severity; and (4) workouts, modifications, and other alternatives to foreclosure. Not long after these survey papers the important topic of the role of credit scores in predicting mortgage loan performance came to the attention of the research community. Avery, Bostic, Calem, and Canner (1996) document the extent to which credit scores are predictive of subsequent loan performance. Avery, Bostic, Calem, and Canner (2000) analyze credit bureau reports, noting omissions, inconsistencies, and regional variation in reporting. Given how predictive credit scores have proven to be in virtually all applications, empirical models omitting them is likely to be seriously miss-specified. Beyond these survey papers and the topic of credit scores, research has focused on particular contract types or other loan features. The following are a few examples.

Phillips, Rosenblatt, and Vanderhoff (1996) use individual mortgage loan histories from 1986 to 1992 to estimate default and prepayment probabilities using multinomial logit methodology. Results differ for 15-year versus 30-year FRMs, and for ARMs. As in most other empirical studies, they report higher rates of prepayment for ARMs but, unlike other studies, they find lower rates of defaults. ARMs are generally thought to have greater default risk since borrowers are exposed to payment shocks if interest rates increase. Of course, if lenders recognize this fact and underwrite ARMs more conservatively, differential default rates may never appear. This is one of the fundamental econometric problems with loan performance studies: performance on loans not made cannot be observed. Very little has been done to rigorously assess this econometric problem.

Deng, Quigley, and Van Order (1996) address the default probability of mortgages originated with zero downpayments, a policy alternative sometimes proposed to boost homeownership levels. They develop a competing risks model estimated using semi-parametric techniques and a large data set of Freddie Mac loans originated from 1976 to 1983 and tracked until 1992. They conclude that the costs of such an initiative would be as high as 10% of the total loans funded, were the additional default risk not adequately priced.

More recently, Capozza, Kazarian, and Thomson (1998) emphasize the distinction between the conditional and unconditional probability of default, characterizing the link between the theoretical models of default and the empirical tests as weak. Theoretical models focus on the unconditional probability of default, which could be most suitably tested using data on the cumulative defaults on mortgage loans over the entire 30-year life of the loans, data which are almost impossible to obtain. In contrast, empirical work generally focuses on conditional probabilities over short horizons, using data which are readily available both at a pool or individual loan level.

Still another issue that is relatively unexplored is the effect of appraisal error (and, perhaps, appraisal fraud) on the mortgage default experience. One may view this as a problem with measurement of original LTV. LaCour-Little and Malpezzi (2003) were the first to address the issue of appraisal quality, claiming that poor quality appraisals may lead to under-stated LTV ratios and, hence, elevated default risk. Recently, Kelly (2006) obtained generally similar results using a nationally representative random sample of FHA-insured loans.

Secondary Financing

Another issue is the possibility, and effect, of subordinate financing. As previously mentioned, commercial mortgages generally prohibit subsequent secondary financing, by means of a "due on further encumbrance" clause. The obvious question is why? Is the default experience for commercial loans that allow subsequent subordinate financing significantly worse than that of loans that prohibit it? To the best of my knowledge, this question has not been studied.

On the residential side, however, with the recent growth in home equity, second mortgage lending has exploded and home equity lines of credit now account for hundreds of billions of dollars of on-balance-sheet credit risk borne by financial intermediaries. Home equity lending was also the original structure of the subprime market segment, where borrowers with poor credit and/or excessive debt levels could recapitalize with home equity secured debt (Weicher, 1997).

LaCour-Little (2004) studies whether junior liens affect first mortgage loan performance, noting that all the theoretical models effectively assume that the borrower has one, and only one, mortgage loan. Junior liens, especially those taken out post-origination, raise the contemporaneous LTV and reduce borrower equity, a term labeled "equity dilution." LaCour-Little (2004) provides some preliminary evidence that borrowers who are more likely to have junior liens are also more likely to eventually default, though this hypothesis has yet to be more thoroughly tested.

Other research has also focused on the home equity lending market segment recently. For example, Agarwal, Ambrose, and Liu (2005) examine home equity lines of credit and find that borrowers taking out such credit lines have an elevated risk of future credit deterioration. Moreover, borrowers who experience negative credit events use higher fractions of their available credit lines. Similarly, Agarwal, Ambrose, Chomsisengphet, and Liu (2005) examine the performance of home equity lines and loans, finding considerable difference in terms of default and prepayment risk. Unfortunately, as with most data on home equity lending, they do not have information about the underlying first mortgage loan. While this is another important area for research, the data requirements to jointly analyze the performance of first and junior loans are quite daunting.[21]

Commercial Mortgage Market

The empirical literature on commercial mortgage loan performance is much smaller than that on the residential segment, though many of the themes and methods are similar. Accordingly, I provide a bit more detail on the papers surveyed below, attempting to link, where applicable, findings to those in the residential segment.

Elmer and Haidorfer (1997) focus on the multifamily segment, analyzing RTC issues from the early 1990s, using cross-sectional time series methods to calculate 12-month conditional prepayment rates as of December 1995 in the range of 13%–18%. Unfortunately, the paper is silent on the extent to which these early contracts contain contract terms limiting prepayment.

Abraham and Theobald (A&T) (1997) develop a simple prepayment model using a sample of 7,800 multi-family mortgages owned by Freddie Mac and originated over the period 1984–1990. Controlling for absence or presence (and type) of prepayment penalty, they find that multi-family has lower prepayment risk at discount coupons and higher prepayment risk at premium coupons (i.e., that multi-family loans have greater interest rate sensitivity compared to single-family). This result would be consistent with the view that options are relatively more ruthlessly exercised in the commercial, versus residential, segment of the market.

Follain, Ondrich, and Singha (1997) address this question directly, using loan-level data on 1,083 multi-family loans originated during 1975–1986 and tracked through

1989 to estimate a mortgage prepayment function. Over the study period, 451 loans prepaid, 20 defaulted, and the balance (over 50%) survived. All were subject to a single prepayment penalty contract provision providing for a penalty of six months interest if the loan was less than five years old and 1% of outstanding loan balance thereafter. While they find that their measure for the option value is positive and statistically significant across models, the implied hazard model predicts relatively low prepayment rates, suggesting relatively less ruthlessness in the commercial market. Prepayment rates never exceed 10% until loan age exceeds ten years even when the option is deep in-the-money.

Maxam and Fisher (1998) focus on pricing effects on CMBS issues backed by multiple property types. In their data, lock-outs preclude rate-driven prepayments but defaults may produce early return of principal to senior security holders. Maxam and Fisher argue that although senior tranches are theoretically immune from prepayment risk, the transformation of default to prepayment risk is evident in the data. This occurs when recoveries on defaults plus the losses absorbed by junior tranches appear as prepayments to the senior tranches.

Kelly and Slawson (1999) use simulation to address the value of delay in the case of commercial mortgages containing prepayment penalties. Their approach extends research showing a value to delay for both default and prepayment options in the single family market. The value of delay occurs because prepayment penalties expire or decline in magnitude over time. Kelly and Slawson show how a step-down penalty structures increases the value of delay, thereby depressing the rate of prepayments even when the option is substantially in-the-money.

Extending this line of research, Fu, LaCour-Little, and Vandell (2003) examine the range of prepayment penalty structures found in actual contracts originated by a major lender during the 1990s. Simulation is used to estimate the value of the prepayment option, at about 5.8% of par value. Hazard models estimated from data on 1,165 multi-family mortgage loans show prepayment rates vary with alternative penalty structures. While stronger provisions are relatively more effective than weaker penalties, none completely eliminates the risk, implying that the assumption that commercial mortgages are entirely immune to prepayment risk is inappropriate.

Much of the empirical research described above has used data from the 1980s–1990s and much of it is multi-family, rather than non-residential. Whether these results extend to the non-residential segment is unclear. Wheeler (2000) argues that as of the late 1990s, variation in prepayment penalties in loans securitized into CMBS had virtually vanished and that full-term lock-outs had become the standard contract provision. While the CMBS market experienced rapid growth during the early years of the new millennium, data on the experience of portfolio lenders still active in this segment is largely missing as is data assessing differential performance across property types, especially the non-residential categories of retail, office, and industrial.

Turning to default in the commercial segment, Vandell, Barnes, Hartzell, Kraft, and Wendt (1993) examine commercial mortgage default using disaggregated loan data.

They find that default is related to contemporaneous loan term, borrower, property, and economic/market conditions. Results confirm many expected relationships, in particular the dominance of loan terms and property value trends over time in affecting default.

Snyderman (1994) provides an empirical analysis of a distressed life insurance company portfolio comprised of loans originated over the period 1973 through 1986 and foreclosed prior to 1991. He estimates an average lifetime default rate of approximately 15%, a high rate probably attributable to the particular data set and time period analyzed. The late 1980s and early 1990s witnessed a substantial decline in commercial property values as a result of the Tax Reform Act of 1986, triggering a surge in commercial mortgage defaults in the late 1980s and early 1990s.

More recently, Ambrose and Sanders (2003) employ a competing risks model to examine the default and prepayment behavior of commercial loans underlying CMBS issues. They find that changes in the yield curve have a direct impact on the probability of mortgage termination. Interestingly, they do not find any relationship between LTV and either prepayment or default. This latter finding could be because of the relatively low level of variation in LTV when maximum allowable levels are low, as is often the case with CMBS. Alternatively, LTV may be endogenous, if lenders vary maximum allowable LTV with other levels of risk.

Methodological Issues

While methodological issues apply most often to empirical analyses, the theoretical literature encounters a number of methodological questions as well, generally related to computational procedures. The major methodological choice for asset pricing purposes is whether to use backward-solving algorithms or forward-solving Monte Carlo techniques. Commercial applications generally use the latter and commercial software[22] is available to price mortgages and mortgage-related assets. In contrast, the theoretical and academic literature tends to employ backward-solving methods. In either case, a term structure model is required, producing multiple questions: (1) one factor, two-factor, or three factor model; (2) how to calibrate to the existing term structure; (3) what assumptions about interest rate volatility should be used, etc. Addressing these questions in further detail is out of scope here, yet essential to modeling mortgage pricing. For more on the effective of alternative interest rates processes on the mortgage valuation, see Archer and Ling (1995).

Methodological issues are abundant and varied in the empirical literature, too. Survival models such as proportional and non-proportional hazard models are generally the preferred choice. Much important work in this area has been done in the biometric field and the analogy is immediate: mortgages may terminate due to default or prepayment and their survival probabilities over time depend both on their fundamental, time-invariant, characteristics, as well as the course of events following origination, such as the trajectory of interest rates or house prices. Under this type of specification, some baseline hazard rate scales up or down as a function of the level of particular covariates, many of which are time-varying. Because of time-dependence, simple time-to-event models will not produce appropriate results because terminations can occur at virtually any point in time and it is the conditions at and around the time of termination that are most relevant. Consequently, accelerated failure time models including only time-of-origination variables as predictors are inappropriate modeling methods.

While time to termination is the dependent variable in the standard hazard model specification, it is the conditional probability of termination at each point in time that is the necessary output value in pricing applications. To accomplish this, data are often transformed into event histories with each unit of observation contributing multiple observations up until termination, or censoring. Termination events are censored if the loan is still active as of the point in time when the data set terminates. Researchers generally specify time in either monthly or quarterly units of observation. Use of quarterly observations works well to pare down very large data sets[23] and has the added advantage of matching to most of the well-known house price indices, which are often used to estimate current loan-to-value ratio. Once so transformed, a variety of modeling techniques can be applied to the data, with the dependent variable becoming termination of loan j at time t, conditional upon survival upon to time $t - 1$. Most of the papers in the following summary noting methodological innovations use the event history format and some variation of the standard hazard model.

The basic set up for the widely used hazard models is as follows. Begin by defining the time to prepayment, T, as a random variable, which has a continuous probability distribution, $f(t)$, with t a realization of T. The cumulative probability is defined as:

$$F(t) = \int_0^t f(s)ds = \Pr(T \leq t), \tag{5}$$

from which the survival function follows as:

$$S(t) = 1 - F(t) = \Pr(T \geq t). \tag{6}$$

The survival function describes the probability that the time to prepayment will be of length at least t. The probability (l) that a prepayment will occur in the next short interval of time, Δt, given that the borrower has not prepaid prior to time t is defined as:

$$l(t, \Delta t) = \Pr(t \leq T \leq t + \Delta t | T \geq t). \tag{7}$$

From this probability, the hazard rate is defined as:

$$h(t) = \lim_{\Delta t \to 0^+} \frac{\Pr(t \leq T < t + \Delta t | T \geq t)}{\Delta t} = \frac{f(t)}{S(t)}. \tag{8}$$

Adding k covariates, some of which may be time-varying, we can write the model as:

$$H_i(t) = \lambda_0(t) \exp(\beta_1 X_{i1} + \beta_2 X_{i2}(t) + \ldots \beta_k X_{ik}). \tag{9}$$

In (9), $\lambda_0(t)$ is the baseline hazard rate, **X** is a vector of covariates, and β is the vector of parameters to be estimated. Finally, taking logs of both sides, we have the model to be estimated by the Cox method of partial likelihood:

$$\log H_i(t) = \alpha(t) + \beta_1 X_{i1} + \beta_2 X_{i2}(t) + \ldots \beta_k X_{ik}. \tag{10}$$

One of the attractions of the Cox model is that the baseline hazard factors out in the estimation of the likelihood function; accordingly, results for the covariates are independent of any particular baseline hazard rate. While this is useful for researchers interested in assessing the effect of a particular covariate on the hazard, it makes model predictions more difficult, since one must assume some particular baseline hazard form.

One approach, consistent with Wall Street conventions, is to simply assume 100% PSA as the baseline hazard rate.[24] Such a pattern is consistent with the household mobility interpretation of the baseline hazard. Once in a new home, given transaction costs, households are unlikely to move during the first two–three years, but as time passes, the probability of a move increases, eventually leveling off at a constant rate of 6% annually. While arguably reasonable for loans originated for home purchase purposes, this rationale breaks down for refinancing loans, since those do not involve household mobility.

One difficulty with the standard hazard model as outlined is that it does not distinguish competing causes for termination; hence, it is suitable for analysis of either default or prepayment but not the two competing risks jointly, either of which could cause early loan termination.[25] One possible solution given data in event history format is the well-known multinomial logit model (MNL), with some function of loan age as a predictive variable. This approach treats each of the several termination causes (default, prepayment due to refinancing, prepayment due to borrower mobility) independently and has been widely used in the literature. MNL has the advantage of readily generating conditional probabilities of the event of interest at each point in time.

The following describes the MNL logit set-up, where borrower mobility is a distinct alternative as in Clapp, Goldberg, Harding, and LaCour-Little (2001). The data for each loan has been restructured to include one observation for each time period during which the loan is active from origination up to and including the point of termination, whether by default, refinancing, or payoff attributable to borrower mobility.

By using indicator variables for time, a flexible baseline hazard may be estimated:

$$h_{it} = \frac{e^{\theta(t)+\beta' X_{it}}}{1 + e^{\theta(t)+\beta' X_{it}}} \Rightarrow \ln\left(\frac{h_{it}}{1 - h_{it}}\right) = \theta(t) + \beta' X_{it}, \tag{11}$$

where h_{it} is the probability of failure for individual i at time t and $\theta(t)$ is the inner product of estimated coefficients and a vector of time indicator variables with one element for each time period in the data. Note that the covariates may be time-varying.

The multinomial logit model provides a logical extension of this reasoning to the competing risks model. The restructured data and the use of $\theta(t)$ to model the baseline hazard generalize from the bivariate logit model. Thus, letting Y_{it} represent the i^{th} borrower's decision at time t, the log-likelihood function is:

$$\ln L = \sum_{t=1}^{T} \sum_{i=1}^{n_t} \sum_{j=0}^{3} d_{ijt} \ln(\Pr(Y_{it} = j)), \tag{12}$$

where, $\Pr(Y_{it} = j) = e^{\theta(t)+\beta_j' X_{it}}/1 + \Sigma_{k=1}^{3} e^{\theta(t)+\beta_k' X_{it}}$ for $j = 1, 2, 3$ and $\Pr(Y_{it} = 0) = 1/1 + \Sigma_{k=1}^{3} e^{\theta(t)+\beta_k' X_{it}}$, where n_t is the number of observations in the restructured data at time t ($t = 1, \ldots, T$), j indexes the possible choices (continue, default, refinance, move), and $d_{ijt} = 1$ when the alternative j is chosen in the i^{th} observation at time t, otherwise it is zero.

Competing risks are included in Equation (12) since probabilities must sum to one. Thus, an increase in the probability of one risk must necessarily be associated with a decline in the probability of at least one other risk. The chief criticism of the MNL model, however, is that the mortgage termination risk setting does not satisfy the independence of irrelevant alternatives (IIA) assumption required, since default and prepayment are substitutes [see Clapp, Deng, and An (2006) for a complete discussion].

Another important methodological issue is how to measure the value of the borrower's prepayment option. Early models typically calculated the difference between the contract rate on the mortgage and the prevailing market rate; other formulations include the ratio of the two rates or the ratio of the market values of the loan to the current book value. More complex formulations address uncertainty in the term structure. For example, Deng (1997) analyzes the competing risks of default and prepayment, allowing for a stochastic term structure and using semi-parametric hazard model methods. The forward term structure is simulated, allowing option values to be computed at each observed mortgage termination point. Deng implements this procedure using a large dataset of Freddie Mac loans, and illustrates how resulting parameter values vary when the term structure is stochastic. A significant methodological issue is that in all cases one must specify a market rate at which the borrower could refinance. Yet the rate at which the borrow can refinance will depend, not on the time of origination loan characteristics but on their financial position (including current housing equity) at the time of the refinancing decision. If the borrower's credit has deteriorated, this may well be at some premium over the market average prime rates[26] typically used.

Use of non-parametric methodologies is another recent empirical innovation. Maxam and LaCour-Little (2001) present non-parametric kernel density regression techniques as a method for modeling mortgage prepayments. Notable in this paper is a comparison between prepayment predictions generated by the model and those produced by a parametric model used by a major mortgage lender during the early 1990s.[27] In related work, LaCour-Little, Maxam, and Marschoun (2002) demonstrate how non-parametric kernel density regression may be used to improve the fit of parametric mortgage prepayment models by identifying inflection points and non-linearities in the data.

Deng, Quigley, and Van Order (2000) is unquestionably the most widely cited paper focusing specifically on mortgage termination risk.[28] It presents a new methodology for estimating a competing risk hazard models while allowing for unobserved borrower heterogeneity. An essential insight of their model is that each observed termination event effectively censors observation of the alternative event. If a loan prepays at month 18, we cannot observe whether it would have defaulted at month 30; conversely, if a loan defaults in month 36, we cannot observe whether it would have prepaid in month 48. In a more traditional hazard model setting, censoring is not assumed to occur until the end of the observation period. In the mortgage context, this means that default and prepayment are assumed to be independent risks, an arguably incorrect assumption. The Deng approach overcomes this limitation, presenting a unified model of competing risks allowing dependence between the two hazards and estimation of their effects jointly, together with estimates of the effect of unobserved heterogeneity. Given the complexity of the joint survival and likelihood functions, we do not reproduce them here.

The Deng, Quigley, and Van Order (2000) model is implemented using a large data set of Freddie Mac loans, jointly modeling the competing risks of default and prepayment, including baseline hazards, the effect of covariates, and unobserved heterogeneity. Overall results generally support the contingent claims model, which predicts a high probability of exercise of financial options when those options are in-the-money. Deng et al. also show that there is a significant heterogeneity among borrowers, particularly with respect to prepayment, implying that less complex models are insufficient. Moreover, failing to model prepayment as a competing risk may result in serious errors in estimating default risk.

More recently, Clapp, Deng, and An (2006) expand the analysis of unobserved heterogeneity to the multinomial logit model, an alternative estimation method that has been popular in the empirical literature, as previously discussed. They characterize models that incorporate unobserved heterogeneity as full information competing risks hazard models. Clapp et al. also classify the literature on mortgage termination risk into papers that focus on termination due to refinance, termination due to household mobility, or termination by default. Some of this classification scheme is included in Exhibit 1.

Innovations in mortgage modeling have been an area of considerable research in recent years, with an entire issue of *Real Estate Economics*[29] recently devoted to the topic. In that issue, Wallace (2005) categorizes models as of two types: rational structural models applied to pool-level data and loan-level, reduced form, or behavioral models.

The former link option exercise to the underlying dynamics of asset prices or interest rates, whereas reduced form, behavioral models emphasize empirical estimation of the timing of option exercise.

On the commercial side, relatively less work has been done. A barrier to progress in empirical modeling has been the lack of a widely accepted index of commercial property values that would allow calculation of a contemporaneous loan-to-value ratio (CLTV). In contrast, on the residential side, researchers routinely use the OFHEO[30] house price index to estimate CLTV by assuming that houses appreciate (or depreciate) at the same rate as the index or use the variance of the index to estimate the probability of negative equity. Much work has been done to develop commercial property indices [see, for example, Geltner and Ling (2005)] and the recent development of a market on the Chicago Mercantile Exchange on which options and futures on house price and commercial property indices trade is an encouraging sign.

Conclusions and Open Research Questions

Dickinson and Heuson (1994) characterized the early work on mortgage prepayments as a coherent body of research that focused on borrower motivations for prepayment, both financial and non-financial, and the effect of those decisions on mortgage and MBS cash flows, yields, and pricing. They also suggested further research in three main areas: (1) borrower motivations; (2) comparative studies; and (3) ex-post returns in the secondary market. Since that time, more complete models have recognized that default and prepayment are substitutes, with the occurrence of one effectively precluding observation of the other. Moreover, econometric techniques have evolved and much of the research is now done using richer loan-level event histories as opposed to time series studies of mortgage pool performance. The effect of additional borrower and loan characteristics, both observable and unobservable, has become of considerable interest.

What have we learned from all of this research? Clearly, option-theoretic methods are the predominant method for assessing mortgage termination risk and valuing the uncertain cash flows promised by mortgage contracts; however, practical considerations and empirical anomalies persist, particularly when these functions are incorporated into valuation frameworks. Econometric techniques have advanced considerably, allowing default and prepayment to be modeled as competing risks. Simultaneously, contract innovations, new technologies, expanded market segmentation, and institutional arrangements have evolved, all of which affect mortgage termination risk while providing fertile ground for further research.

Despite the extensive research on mortgage termination over the past fifteen years, many questions remain unanswered, including the following almost certainly incomplete list:

1. To what extents are mobility differences the real source of borrower heterogeneity, that is, if borrowers never moved, would we still observe significant and unexplained differences in prepayments?

2. Given that borrowers can reduce their equity with junior liens post-origination, how much of the error in predicting default is attributable to errors in measurement of current equity, as opposed to, say, borrower heterogeneity in the exercise of the default option?
3. What role does the threat of recourse play and how often is that lender option actually exercised? Similarly, to what extent do lenders differ in terms of their propensity to exercise the foreclosure option, versus work-outs and other alternatives, and how do those differences vary across market segments, loan, and borrower types?
4. What role does appraisal quality play in predicting future loan performance, especially default? How does the industry trend toward limited or automated collateral valuation in the residential market affect outcomes?
5. Have the constraints on prepayment declined with the development of the subprime market? By extension, can borrowers encountering financial difficulties now prevent, or at least delay, foreclosure by refinancing into the subprime market?
6. What will be the early termination experience with alternative mortgage designs, such as the hybrid ARM, payment-option ARM, and interest-only products?

On the commercial side, the research is much more limited, so opportunities for significant contributions abound. Outstanding questions include the following:

1. Is the exercise of mortgage options really more ruthless as compared to the residential segment?
2. To what extent will development of an index of commercial property values allowing CLTV calculation improve models of commercial mortgage default?
3. To what extent are trigger events (e.g., unexpected vacancies) necessary to adequately explain the default experience in the commercial sector?
4. What economic and institutional factors explain the difference in the contract structure of commercial mortgages versus residential mortgages?

While we have learned much about mortgage termination risk over the past decades, ongoing research is essential to address these and new, as yet unknown, questions.

Endnotes

1. All figures from *The Market Pulse*, a publication of LoanPerformance, a commercial provider of market-wide default and prepayment rates on residential mortgages (www.loanperformance.com).
2. Serious delinquency is defined as 90-days or more delinquent or in the process of foreclosure and hence generally considered a measure of the default rate. Not all of these defaults will proceed to foreclosure, however.
3. These rates are 3-month CPR (conditional prepayment rate), that is, the rate of loan payoff in dollar terms over a three-month period annualized.

4. According to 2006 census data, about 14% of the population changes address each year; however, renter mobility is much higher than that of home owners. Home owner mobility was about 7.5% in 2005. (Source: U.S. Census Bureau, Current Population Survey, 2005 Annual Social and Economic Supplement.)
5. Federal Reserve data on commercial mortgages held by banks; delinquency defined as more than 30-days past due. Source: http://www.federalreserve.gov/Releases/chargeoff/delallsa.htm Accessed Feb. 27, 2007.
6. Third-party originators are both mortgage brokers and loan correspondents; the latter originate loans in their own name, promptly re-selling them to other primary market players, whereas brokers act as intermediaries matching borrowers and lenders but do not lend their own money. Brokers have become increasingly important in the loan origination process over time and originate more than 60% of all loans.
7. Eighty percent is a common maximum on many types of commercial mortgages, though there are exceptions. Maximum loan terms seldom exceed 10 years (e.g., 30 years amortization with a 10-year due date).
8. Federal Reserve, Flow of Funds, Table L.2 Credit Market Debt Owed by Nonfinancial Sectors.
9. Total securitized GSE pools account for $4.0 trillion, the category of asset-backed securities adds another $3.6 trillion, but this includes some non-mortgage assets (e.g., securitized auto and credit card loans).
10. GNMA guarantees payments of interest and principal on loan pools containing government-guarantied mortgage loans, principally FHA and VA. Unlike Freddie and Fannie, GNMA does not actually own the loans.
11. Hardin, Liano, and Chan (2006) rank individual papers and authors based on citations in the three top real estate journals. Tied with one other paper, Kau and Kim (1992) ranks sixth in this ranking.
12. See Cox, Ingersoll, and Ross (1985).
13. Burnout is the tendency for higher coupon loans contained within a pool to prepay first, leaving behind lower coupon (or perhaps less rate sensitive) loans, altering pool performance over time. See further discussion in the empirical section.
14. "Ruthless" models assume that borrowers always exercise the option, once it is in-the-money.
15. This important paper is included even though it is prior to our usual 1992 starting point, noting that it was not included in the earlier survey article mentioned.
16. Wall Street investment houses produce numerous reports detailing actual prepayment rates for mortgage-backed pools, generally expressing in terms of conditional prepayment rate (CPR) or relative to the PSA benchmark standard. In such reports a 50% CPR rate is very fast and "normal" rates are on the order of 10% CPR.
17. Although the probability of moving may depend indirectly on the value of the prepayment option (i.e., when the option is deeply out-of-the-money, borrowers are "locked in" to their current house and will be less likely to move). Early research not surveyed here addressed this topic in considerable detail and it was especially germane for borrowers with loans originated during the early 1970s during the relatively high rate 1980s.
18. Seasonality has been observed in aggregate prepayment rates, since households tend to move more often in Spring and Summer, producing greater housing turnover.

19. Debt on owner-occupied housing is non-recourse as a matter of law in only the minority of states; moreover, non-recourse protection generally applies only for the original home purchase loan, not for subsequent refinancing loans.
20. Debt relief occurring as a result of foreclosure may trigger income taxes for the defaulting borrower.
21. Property level data showing liens by property would have to be merged with credit repository data showing mortgage debt by borrower.
22. The SalomonSmithBarney Yield Book is the original application; Mortgage Industry Advisory Corporation's WINOAS product provides a newer, and more open, technology. QRM also offers related products.
23. Data sets explode in size quickly under the event history format, since the number of observations is now the number of loans (or pools) multiplied by the number of time periods available.
24. The Public Securities Administration (PSA), predecessor to the Bond Market Association and now the Securities Industry and Financial Markets Association, established the PSA standard for measuring prepayment speeds. One hundred percent PSA implies a linear monthly increase in prepayment speed over the first 30 months of mortgage life, followed by a constant rate of 6% CPR thereafter. Wall Street conventions often describe a pool as having speeds equivalent to some multiple of PSA (e.g., 200 PSA). In the TBA market, this usually means that the current bond price is consistent with this prepayment speed assumption assuming static interest rates. For seasoned pools, however, it may mean that the current empirical prepayment speed, if annualized, is equivalent to some PSA multiple.
25. Depending on the data, sometimes this does not matter. Default is such a rare event, relative to prepayment, that often there are not enough observations to even model it.
26. The Freddie Mac Primary Mortgage Market Survey rate is one such example that has often been used.
27. The lender prepayment model described uses an arctangent functional form, a popular method to capture the non-linear shape of the prepayment function.
28. This paper, published in *Econometrica*, is tied for first place in a citation count from the top three real estate journals according to Hardin, Liano, and Chan (2006).
29. Volume 33(4), Winter 2005.
30. The Office of Federal Enterprise Oversight (OFHEO) publishes a quarterly price house price index at both the state and MSA level, which can be readily used to mark LTV to contemporaneous levels.

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